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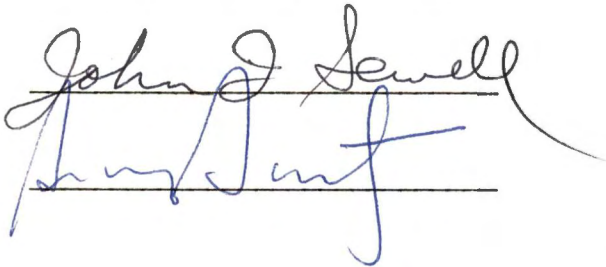
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I am submitting herewith a thesis written by John Dardis Simmons entitled "Quality Analyses of Surface Runoff from Agricultural Lands." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

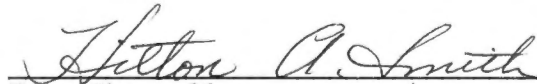


C. H. Shelton, Major Professor

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QUALITY ANALYSES OF SURFACE RUNOFF
FROM AGRICULTURAL LANDS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Dardis Simmons

March 1976

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ABSTRACT

Soil erosion by water has an adverse effect on everyone. Users of water from receiving streams or reservoirs often suffer loss of unpolluted water as a result of turbidity and sediment. Farmers suffer loss of topsoil, loss of natural and applied fertility, and loss of income. The purpose of this study was to establish a relationship between the soil erosion process and selected parameters of water quality. The study was conducted on three watersheds at the Milan Field Station and two at the Middle Tennessee Agricultural Experiment Station near Spring Hill. Runoff samples were collected from each watershed by an automatic pumping sampler and analyzed for sediment concentration, total suspended matter, and turbidity.

Work was done to develop a relationship between sediment concentration and selected hydrologic parameters. Sediment data were developed for runoff-producing rainstorms occurring on each watershed. Linear regressions produced a good relationship between sediment weight and the kinetic energy associated with rainstorms. Using sediment as the dependent variable and the rainfall-erosion index as the independent variable, an empirical sediment prediction equation was developed for three of the five watersheds. Using cropping-management and soil-erodibility factors, a single prediction equation applicable to all five watersheds was formed. The equation tested favorably with data from two test watersheds as well as with data derived from the universal soil-loss equation developed by Wischmeier and Smith.

Sediment concentration, total suspended matter, and turbidity were related to various conditions of rainfall, runoff, and land use. Average monthly values of rainfall maximum 30-minute intensity, peak runoff rate, turbidity, total suspended matter, and sediment concentration were compiled from one watershed at Milan. The data were analyzed for trends over a period of one year. A poor relationship was found between the water quality parameters and rainfall-runoff values during the growing season. However, the analysis indicated a good relationship for the dormant season. Concentrations of the selected water quality parameters reached maximum values during months when maximum tillage and minimum vegetative cover were prevalent.

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CHAPTER I

INTRODUCTION

I. BACKGROUND AND STATEMENT OF THE PROBLEM

The agricultural industry, however important to society for food and fiber, also has a by-product of water pollution. Because of increasing public concern, agriculture in Tennessee has recently been forced to operate under more strict water quality standards established by the Environmental Protection Agency and the State of Tennessee Water Quality Control Board. These standards have caused farmers to become increasingly concerned about the pollution potential of water leaving their operation. A knowledge of the relationship between concentrations of certain water quality parameters and rainfall, runoff, land-use and management practices is essential for the proper supervision of agricultural field operations to protect quality of the water resource.

Sediment, the major pollutant on a volume basis, consists of fine, light soil particles which are transported by runoff and stream flow. Generally, therefore, sediment is high in clay, silt, and organic matter. To the farmer, sedimentation represents loss of top-soil, loss of applied and natural fertility, loss of productivity, and subsequent loss of income. Hadley and Lusby (16) recorded a soil loss of 40.3 tonnes per hectare from a 4.9 hectare watershed in western Colorado as the result of a summer storm in which the maximum intensity was 5.0 centimeters per hour. In a rare occurrence, Wischmeier (45)

observed a soil loss of 497 tonnes per hectare during an extremely large storm (200-year return period) which had an intensity of 15.2 centimeters per hour. The storm occurred at Guthrie, Oklahoma in 1949, nine days after cotton had been planted on an 8 percent slope without conservation practices. Loss of topsoil from the plot totaled 3.3 centimeters.

On a much larger scale, Grant (12) reports that on 3.6 million hectares of land converted to farm land in 1974, 42.6 million tonnes of soil were removed by water. Kentucky and Tennessee had 145,80 hectares of this converted land which suffered up to 89 tonnes per hectare per year soil loss. It is imperative therefore that a method be made available for farm managers to predict sediment as a result of land-use and management practices. Soil loss estimation on a yearly basis is possible with the use of the universal soil loss equation developed by Wischmeier and Smith (48), but this method was not intended to be applicable to a single storm or short season to predict pollution.

An important aspect of controlling sedimentation is the effect of such control on farm income. From the results of a 1969 study at Forest Glen, Illinois, Narayanan and Swanson (30) concluded that farm income increases at a decreasing rate as sediment loss increases.

Sediment, as a pollutant, affects the general public in various ways. Sedimentation includes three basic processes: detachment, transportation, and deposition of soil material. Anderson (2) states that during sedimentation, suspended sediment accounts for 80 percent of the total sediment, while bed load makes up the remaining 20 percent.

Charged clay particles and organic matter in sediment have a great capacity for adsorption of pathogens, viruses, plant nutrients, pesticides, and other chemicals. Phosphorus, one of the primary causes of eutrophication, is readily adsorbed onto and transported by soil particles eroded from fertilized land. Nitrogenous fertilizers, the other primary cause of eutrophication, also leave land adsorbed on sediment during erosion. Schuman et al. (38) found in a study involving six watersheds in southwestern Iowa that, after applying nitrogen fertilizer, 92 percent of the nitrogen lost by all methods was lost by adsorption on sediment removed by water.

ref? People far removed from the source of the sedimentation problem have interests in water quality for many reasons. In 1968, the National Technical Advisory Committee developed raw water quality criteria for public water supplies. With regard to sediment and turbidity, the committee made the following decision: (1) sediment and turbidity must be readily removable by coagulation, settling, and filtration; (2) sediment and turbidity must not be present in quantities that will overload a treatment plant; and (3) removal of sediment and turbidity must not cause unreasonable costs.

Water quality criteria established for recreation areas were defined from the standpoint of public health. Participants in water-contact recreation always ingest some water. This may be hazardous because pathogenic micro-organisms that can cause illness and toxic concentrations of chemicals can be adsorbed on sediment suspended in the recreational water (6). Supporting concerns of sportsmen, Ritchie (36) states that fish die from sediment clogged gills at sediment levels

of 175,000 ppm. He further states that sediment reduces fish egg survival and reduces the ability of fish to locate food. The problem is of such scope that the Federal Water Pollution Control Act Amendments of 1972 include sediment along with other pollutants in stating that it is the national goal to eliminate discharge of pollutants into navigable waters by 1985. The federal government, therefore, places the burden on the farmer to acquire knowledge of how his land-use and management practices affect the quality of water in those reservoirs which receive runoff from his operations. Preventing violations of water quality regulations should be included in proper management of modern agricultural operations.

In a general sense, Schumn (39) indicates that the need for data concerning erosion processes is pressing, not only as a guide for better land management, but also as a basis for explaining land forms as functions of current erosion processes and erosion rates.

The purpose of this study was to investigate hydrologic and land-use effects on concentrations of sediment, total suspended matter, and turbidity found in runoff from agricultural lands. Data were obtained from runoff samples taken from five small agricultural watersheds during 1974 and 1975.

The investigation was conducted concurrently with representatives of the Plant and Soil Science Department who analyzed the same samples for additional water quality parameters including nitrates, phosphates, ammonia, chlorides, and dissolved solids.

II. RESEARCH OBJECTIVES

Objectives of this study were:

1. To relate concentrations of sediment, total suspended matter, and turbidity to various conditions of rainfall, runoff, and land-use practices; and
2. To develop a scheme to predict sediment resulting from individual rainfall events on ungaged watersheds.

CHAPTER II

REVIEW OF LITERATURE

The water quality parameters under investigation were sediment concentration, total suspended matter, and turbidity. The sources and measurement of the water quality parameters, as well as their relation to rainfall and runoff, have been frequently reported in the literature.

I. SEDIMENTATION

Effect of Rainfall on Sedimentation

Raindrop impact is the primary source of energy for detaching soil particles. Impact velocity is usually terminal velocity (44). Wischmeier and Smith (48), working with drop sizes and terminal velocities, developed the following equation to describe the energy of rainfall for a given storm intensity:

$$y = 916 + 331 \log I$$

where y = rainfall kinetic energy in foot-tons per acre-inch, and

I = rainfall intensity in inches per hour.

This, with the storm's maximum 30-minute intensity, form the EI variable which is an integral part of the universal soil-loss equation. The universal soil-loss equation as given by Wischmeier and Smith is:

$$A = R K L S C P$$

where A = the average annual soil loss in tons per acre per year,

R = the erosive-potential rainfall factor,

K = the soil-erodibility factor,

LS = the topographic factor,

C = the cropping-management factor, and

P = the conservation-practice factor.

The rainfall factor, R, is a result of the rainstorm energy-intensity variable, EI, and has been determined for specific zones throughout the United States. Typical values for rainfall energy reported by Wischmeier and Smith (47) were: light rain (0.1 cm/hr), 12.7 m.t/ha.cm; and cloudburst (10.0 cm/hr), 3045 m.t/ha.cm.

Gray (13) indicates that raindrop energy can also be described by the classic equation:

$$KE = 1/2 m V_d^2$$

where KE = the kinetic energy in joules,

m = the mass of the drop in kilograms, and

V_d = the drop velocity in meters per second.

Using this equation, Lull (26) determined similar values to those of Wischmeier and Smith. Typical values reported by Lull were: light rain (0.1 cm/hr), 11.8 m.t/ha.cm; and cloudburst (10.0 cm/hr), 3226 m.t/ha.cm.

The energy contained in a large storm is considerable, and a common summer thunderstorm in Tennessee may well have a dead weight of over 224 tonnes per hectare. Velocities of raindrops may be as much as 32 kilometers per hour; consequently the energy expended on the soil by the rainfall may be as much as 7.3×10^6 meter.kilograms per hectare (18).

The total amount of eroded material which is transported from a source to a downstream control point is known as sediment yield (11). McGuinness et al. (28) found direct correspondence between sediment yield and the rainfall-erosion index (EI) developed by Wischmeier and Smith. Wischmeier (45) adds that since the energy for rainfall comes from falling raindrops, sedimentation from an unprotected field is directly proportional to the values of the rainstorm EI parameter.

Gottschalk (11) states that, other conditions being equal, sediment as a result of runoff will be greatest from watersheds subjected to the most intense rains.

Investigators have also developed relationships between storm size and sedimentation, where storm size was determined by peak intensity rather than energy. After a study of soil loss on 13 midwestern watersheds, Hoyt and Troxell (22) concluded that, with all other conditions constant, sediment was generally greatest as a result of those storms with the greatest intensity.

Piest (33) states that more total sediment will be attributed to moderate storms because of their number, but in an isolated instance a high intensity storm can produce massive sedimentation. He warns of the danger of placing the large storm as a sediment contributor in an improper perspective. From a study involving 72 small watersheds in 17 states, he concluded that the largest percentage of sediment yield was caused by moderate storms with a return period of less than one year.

In a study of seven watersheds throughout the country, Wischmeier (45) found that the bulk of sediment can be attributed to

the more numerous moderate storms that have at least a 50 percent probability of occurrence in any one year. However, Schwab et al. (40) state that one or two high intensity rains frequently cause as much sediment yield as all other storms during a season.

Effect of Runoff on Sedimentation

A sizeable number of investigations were conducted on the relationship of runoff to sedimentation, but the authors could not ignore precipitation. Piest (33) obtained good correlation between runoff rate and sediment yield from two watersheds in Mississippi, but added that experience indicated this was not the general rule with most watersheds. He continued to state that sediment quantities related with more reliability to rainfall parameters than they did to runoff parameters.

McGuinness et al. (28) recorded an excellent relationship between rainstorm parameters and sediment yield, and pointed out the particularly poor relation observed between runoff volume and sediment yield.

Using regression equations to predict change in gully area with both linear and logarithmic models, Beer and Johnson (5) found their precipitation variable to be of much more significance than their runoff variable. The precipitation variable was deviation from the normal monthly total in inches, while the runoff variable was surface runoff in inches. From a study involving eight paired drainage basins at Badger Wash, Colorado, Lusby (27) concluded that the reduction of sediment yield was not directly related to the reduction of runoff volume.

Some authors found runoff to be an acceptable parameter with which to compare sediment yield. In a study of sedimentation in the Pacific Coast basins of western Oregon and California, Anderson and Wallis (3) were satisfied with the relationship they found between sediment yield, runoff rate and runoff volume. They reported that differences in the total volume of runoff produced differences in sediment yield by factors as high as 11.7. In a further test, they reported that differences in the runoff rate produced differences in sediment yield by as much as a factor of 3.6.

Guy and Ferguson (15), in an analysis of sediment movement in seven basins in the eastern United States, concluded that stream sediment concentration during a storm runoff increased significantly as runoff rate increased. They used runoff total volume as a measure of storm magnitude and peak runoff rate as a measure of storm intensity. Guy (14) compared runoff volume to total sediment lost from a 23.5 hectare residential watershed under construction. He reported a soil loss of 235 tonnes as a result of 2.2 centimeters of runoff.

Effect of Land Use on Sedimentation

The agents of soil erosion are water, wind, ice, and gravity; but human activities aggravate the situation and permit these basic agents to perform their function with greater ease and efficiency. The most dramatic increase in sediment yield occurs following urban development or construction.

In Fairfax County, Virginia, Holeman and Geiger (19) recorded soil losses resulting from runoff on a 37.5 square kilometer watershed

undergoing urban construction. In one year 9 percent of the watershed was converted from agriculture to urban development. The sediment yield during this period increased by a factor of 3.0. From a 23.5 hectare watershed undergoing urban construction near Kensington, Maryland, Guy (14) measured a sediment yield of 235 tonnes as a result of a single cloudburst.

Next to urbanization, cropping practices seem to have the largest effect on sedimentation. In an erosion study conducted throughout the Georgia Piedmont, Barnett et al. (4) found close-grazed first year fescue an excellent erosion control crop. Rainfall was 130 centimeters, the erosion index, EI, was 387 and soil loss was only 1.8 tonnes per hectare. Second year fescue provided even better protection. Rainfall was 136 centimeters, the erosion index, EI, was 301 and the soil loss was a very low 0.14 tonnes per hectare.

Lusby (27) indicated, however, that overgrazing can be detrimental to erosion control. As a result of a study conducted in western Colorado, he concluded that heavily grazed watersheds as compared to lightly grazed watersheds produce lower infiltration rates, higher runoff rates, and greater sediment yields due to soil compaction by the livestock.

After a runoff-erosion study conducted near Hastings, Nebraska, Dragoun and Kuhlman (9) concluded that surface runoff and erosion were reduced by lighter grazing and selected tillage practices such as contour furrowing and eccentric disking.

Numerous authors have indicated important relationships between tillage methods and possible sediment yield. After studying runoff and

erosion in the unglaciated area of Iowa, Minnesota, and Wisconsin, Sartz (37) stated that runoff from tilled land can be as much as 10 times greater than from pasture. Soil loss can be as much as 100 times greater.

Burwell et al. (7) observed sediment yield as a result of mulch tillage and minimum tillage versus conventional heavy tillage. They determined that mulch and minimum tillage create conditions conducive to infiltration and storage while traditional tillage often restricts infiltration. They noted that while infiltration was high on well-tilled land before runoff, mulch till provides higher infiltration during runoff.

Glymph (10) investigated the role of sheet erosion in connection with sedimentation, and concluded that sheet and rill erosion accounted for 90 percent or more of the sediment yield. Leopold et al. (25) supported Glymph's conclusion. In researching channel and hill slope erosion, they found that sheet erosion was responsible for most of the sediment yield.

Wischmeier (46) offered suggestions for counteracting the effects of sheet erosion. He investigated conservation tillage as a means of controlling water erosion, and drew the following conclusions:

1. Roughing induced by tillage increases infiltration.
2. Residue incorporation improves infiltration.
3. Mulching keeps infiltration rate high.
4. Runoff velocity is reduced by ridging on the contour.
5. No-till planting decreases erosion substantially.

Several authors investigated some seldom-thought-of effects of land use on sedimentation. Hall and Pawlus (17) reported increased soil losses due to a decrease in soil cover resulting from the increased use of herbicide. Striffler (42) indicated that eroding stream banks represent a source that the land manager can effectively control with cover crops. Forest fires which remove all cover are the cause of substantially escalating sediment yield (11, 35, 20).

II. TOTAL SUSPENDED MATTER

Total suspended matter is also referred to as filtrable residue. In water quality investigations, the amount of material dissolved or suspended in the water is frequently of concern. Such material is almost always complex in nature, requiring long, tedious analyses for complete definition if possible at all. With sediment samples it is difficult and usually unnecessary to distinguish between filtrable and nonfiltrable residue (1). Residue determinations are subject to loss of volatile organic matter and ammonium carbonate, resulting in measurements which are too low. The effect tends to be more pronounced with sediment samples than with sewage samples (31).

III. TURBIDITY

Turbidity is a measure of the optical interferences due to fine suspended matter in a sample. Sediment, which directly causes problems to aquatic life, also causes high levels of turbidity. Trautman (43) states that regardless of sediment, turbidity itself prohibits the penetration of light thereby preventing development of aquatic

vegetation, fish food, fish eggs, and young fish.

Turbidity is in some way related to the amount of suspended matter in a sample, but the authors in the literature reviewed were not in complete agreement as to how exact or valuable the relation might be. The American Public Health Association (1) maintained that it was impractical to correlate turbidity with suspended matter because the optical properties of particulate materials bear little direct relationship to concentrations or specific gravity of the suspended matter. Powell (34) stated that attempts to relate turbidity and quantities of suspended and colloidal materials in water are meaningless due to the inconsistency of any particulate material to diffuse or diminish light repeatedly at any constant rate.

Hornbeck and Reinhart (21) concluded that rough estimates of sedimentation could be determined from turbidity. They derived erosion rates by assuming that parts per million (ppm) sediment was roughly equivalent to turbidity in Jackson Turbidity Units (JTU). Kunkle and Comer (24) conducted an investigation in northern Vermont involving sediment and turbidity measurements over a two-year period. As a result they derived the empirical formula:

$$C_s = 5.32 \text{ JTU}^{1.32}$$

where C_s = sediment concentration in milligrams per liter (ppm).

They admitted, however, that the formula was only applicable to their particular watershed and separate sediment-turbidity relationships must be determined for each independent watershed.

Considering the previous review related to the sedimentation process, it appears well within the realm of possibility to develop a scheme to predict sediment yield. If a universal prediction equation be unobtainable, an empirical relationship appears to be a certainty. Relating the water quality parameters of sediment concentration, total suspended matter, and turbidity to hydrologic conditions and land-use practices would also seem to be quite possible.

CHAPTER III

PROCEDURE

The procedure followed in this study consisted basically of collecting and analyzing selected rainfall, runoff, watershed, and water quality data from five watersheds used for other hydrologic investigations. The nature of the watersheds and their treatments precluded use of statistical designs involving replications. Emphasis was given to establishing a relationship between sediment yield and selected climatic and watershed variables.

I. DESCRIPTION OF WATERSHEDS AND VARIABLES

Watersheds

The five study watersheds included two on the Middle Tennessee Agricultural Experiment Station near Spring Hill and three on the Milan Field Station in West Tennessee. These sites were chosen because most instrumentation needed was already installed on the watersheds. Automatic recording rain gages and stream gages, essential for this study, had been in operation on the watersheds for several years.

In 1974 and 1975, watershed 7 (27 hectares) at Milan contained woods, cotton, corn, and soybeans; whereas in 1974 watershed 15 (14.5 hectares) at Milan was planted in cotton. During this time watershed 15 was subjected to conventional tillage with row direction disregarding slope. In 1975 this watershed was planted in wheat. Watershed 8 (3.7 hectares) at Milan was planted predominantly in cotton and soybeans in 1974, followed by wheat in 1975.

In 1974 watershed 6 (80.4 hectares) near Spring Hill was in grasses for hay production, permanent pasture and grain sorghum. This watershed was used for pasture, hay, wheat and soybean production in 1975. Watershed 5 (4.9 hectares) near Spring Hill was in pasture for beef cattle in 1974 and 1975. A more complete description of the watersheds is found in Table 1.

Variables

Hydrologic variables measured were rainfall intensity (cm/hr) and runoff rate (cm/hr). Water quality variables measured were sediment concentration in parts per million (ppm), total suspended matter (ppm) and turbidity in Jackson Turbidity Units (JTU). Sediment concentration, used in calculations of sediment yield, was expressed in milligrams per liter, which is equivalent to parts per million. A more detailed procedure of the calculations involving sediment is given further in the text.

II. INSTRUMENTATION AND DATA COLLECTION

Rainfall

Rainfall data were obtained with the use of continuous recording rain gages. These rain gages were kept in calibration by comparison with an adjacent U. S. Weather Bureau standard 20.3 centimeter rain gage. The rain gages were located either on or within one quarter mile of each watershed. Rain gage 5 served watershed 5 and 6, while rain gage 7 served watersheds 7, 8, and 15.

TABLE 1. Description of watersheds.

Water-shed	Location	Physiographic Province	Area (ha)	Avg. Slope of Watershed %	LAND USE		Predominant Soils
					Woods	Pasture	
5	Spring Hill	Central Basin	4.9	5	0	100	Armour Captina Maury
6	Spring Hill	Central Basin	80.4	6	1	33	Armour Huntington Maury
7	Milan	Gulf Coastal Plain	27.1	3	25	0	Granada Loring Memphis
8	Milan	Gulf Coastal Plain	3.7	3	0	0	Calloway Henry Loring
15	Milan	Gulf Coastal Plain	14.5	2.5	0	0	Collins Loring Memphis

Runoff

Runoff data were recorded by continuous stream gages. The stream gages consisted of either weirs or a flume accompanied by an automatic water level recorder. Triangular weirs (Figure 1) were installed on watersheds 5, 6, 7, and 8; while watershed 15 was equipped with a 4.5 foot H-type flume (Figure 2). This type flume, preceded by a drop inlet, is self cleaning and minimizes maintenance required to remove silt and debris from the approach channel. For this reason, an H-type flume was installed on watershed 15 which was expected to yield high sediment loads. The weirs and the flume were so constructed that they were precalibrated to provide measures of flow rates from readings of stages. Stage was recorded by Stevens A-35 continuous water level recorders (Figure 3).

Runoff Water Samples

Water samples were obtained with automatic pumping samplers. Product Manufacturing Company PS-69 pumping samplers (Figure 4) were installed on watersheds 6, 7, 8, and 15. On watersheds 6, 7, and 8 the inlet tubes were placed approximately 10 feet up-stream of the weir at the water level recorder stilling well intake. The inlet tube of the sampler installed on watershed 15 was placed in the approach channel approximately 4 feet up-stream of the flume. Water samples were obtained from watershed 5 by an Instrument Specialities Corporation (ISCO) model 1390 pumping sampler (Figure 5). The inlet tube was placed approximately 10 feet up-stream of the weir at the water level recorder stilling well intake.

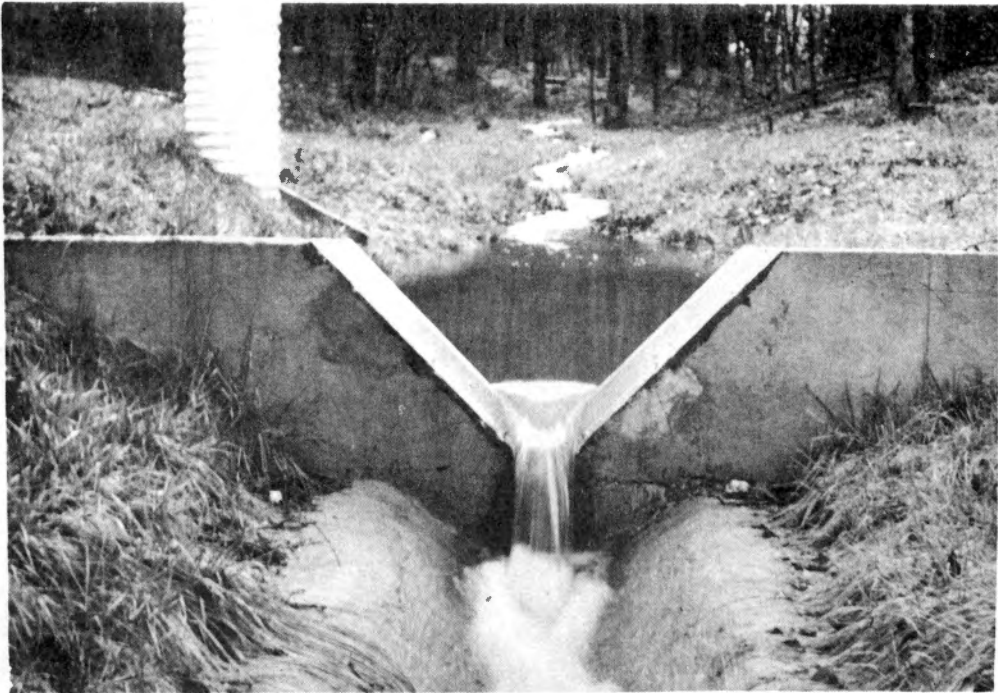


FIGURE 1. Triangular weir.

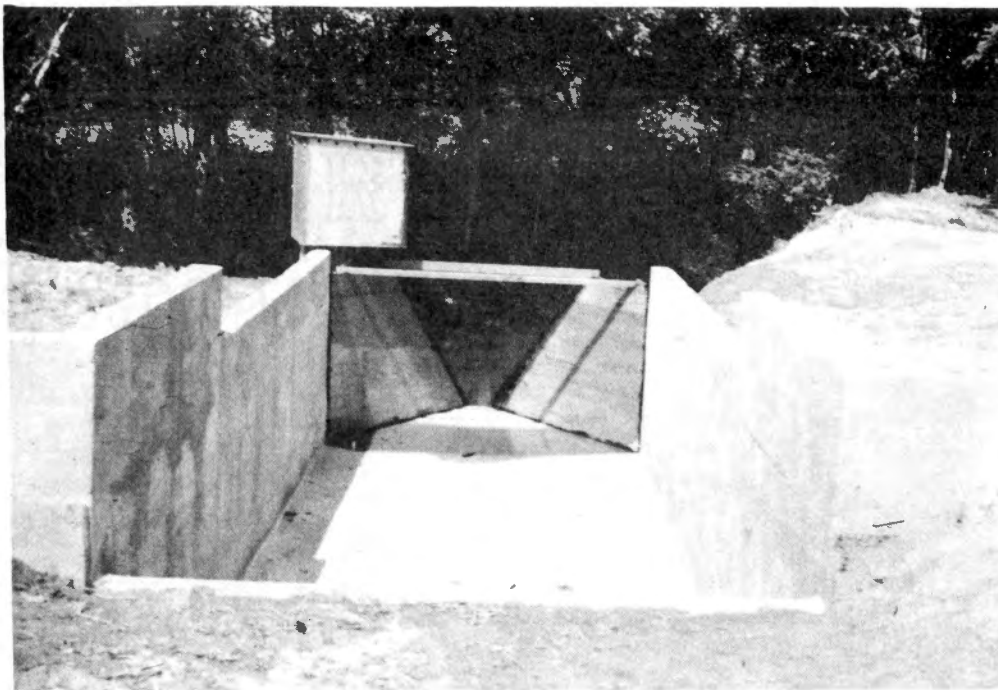


FIGURE 2. H-type flume.

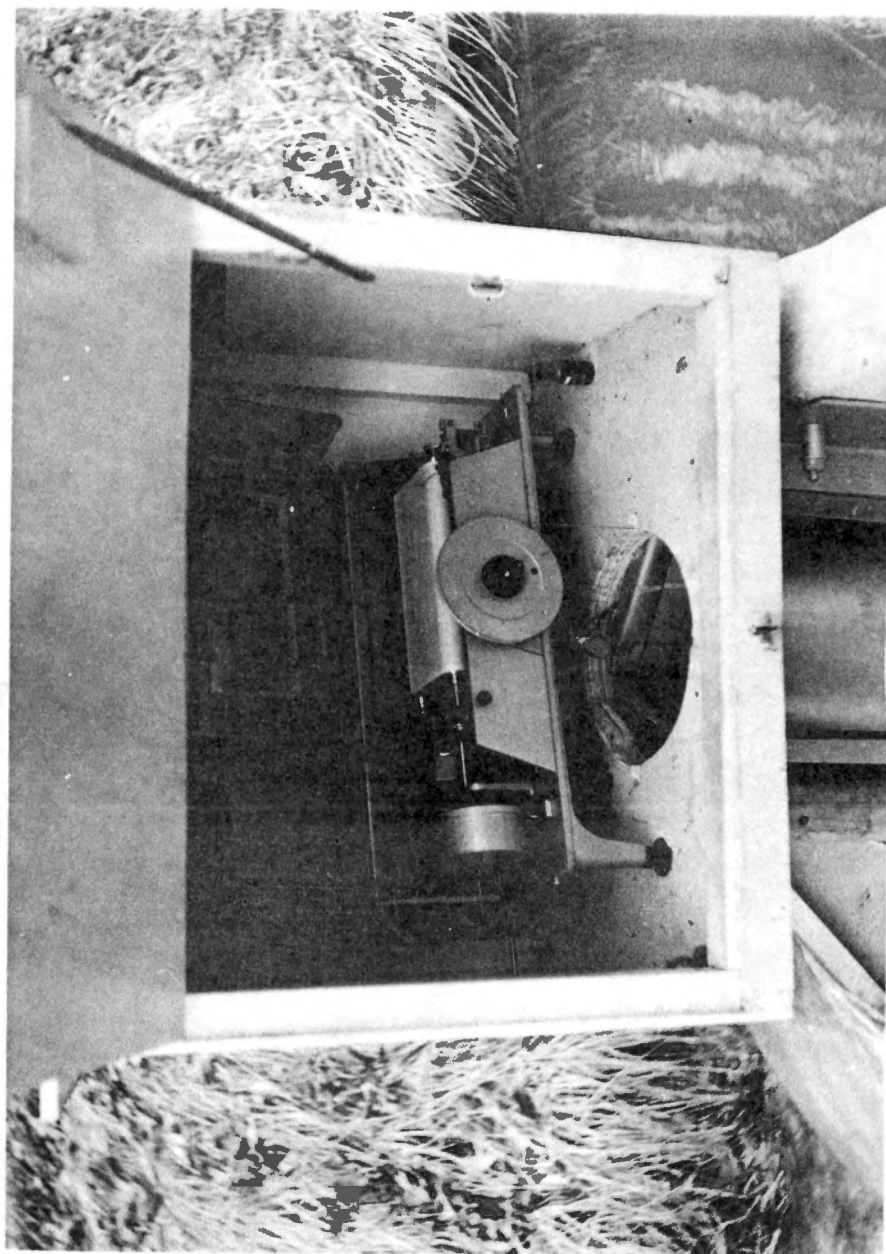


FIGURE 3. Stevens A-35 water level recorder.

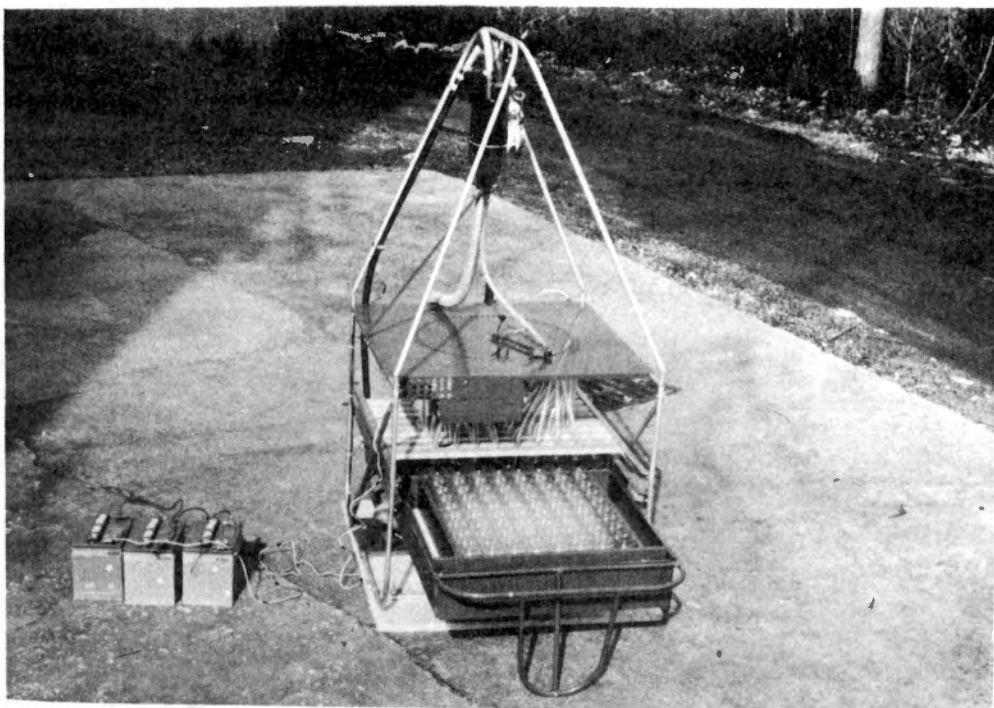


FIGURE 4. Product Manufacturing Company PS-69 pumping sampler.

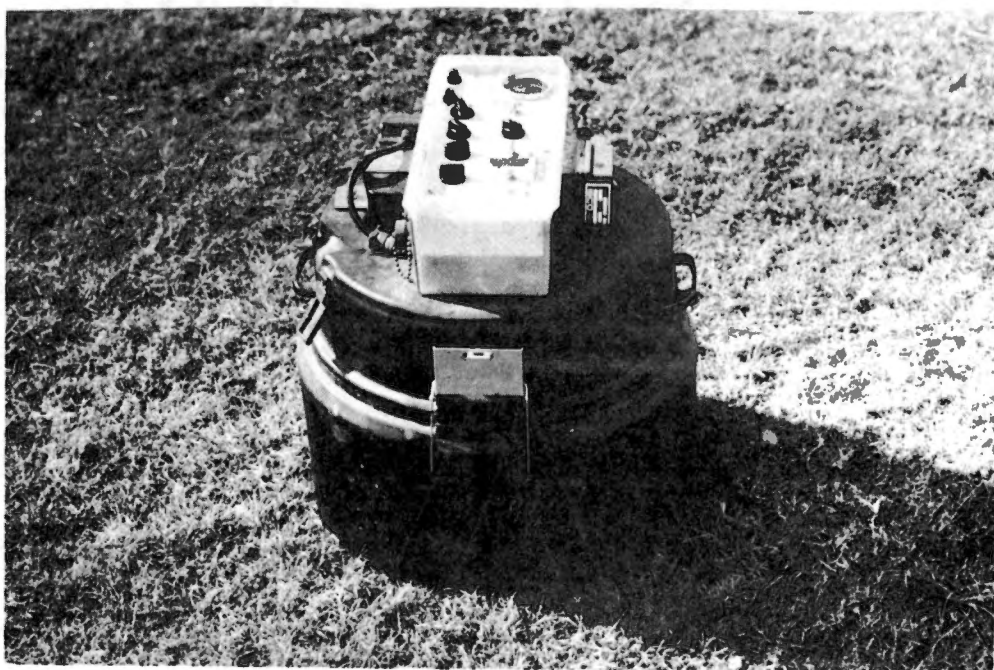


FIGURE 5. ISCO pumping sampler.

To facilitate year-round operation and prevent freezing, the pumping sampler installation on watershed 15 was heated during the winter. Operation of all other pumping samplers was discontinued from November through March.

The PS 69 sampler had the capacity to take 72 one-pint samples continuously at various time intervals. The machines were set to start when the depth of flow reached 6.1 centimeters and to take one sample every half hour as long as flow exceeded this depth. The ISCO sampler had the capacity for taking only 6 one-pint samples. This machine was also set to take a sample every half hour while the depth of flow remained above 6.1 centimeters. Data obtained with the use of the ISCO sampler was incomplete because there was no event marker on the water level recorder used with this sampler. An event marker, a device used with the PS 69 samplers, placed a mark on the chart of the Stevens water level recorder to indicate the time a sample was drawn (Figure 6). This provided a time and runoff rate associated with a particular sample. Data thus obtained were used to determine sediment associated with a specific rainfall-event. More detailed procedure is given further in the text. The water samples were removed from the sampling machines within hours following a rainstorm and frozen for future analysis. At a convenient time, the samples were transported in a portable freezer from the site freezer to a laboratory freezer.

Every sample was analyzed for sediment concentration, but only those samples at or near the peak runoff stage were analyzed for turbidity and total suspended matter. This was done because the major emphasis on water quality was placed on pollution due to sedimentation.

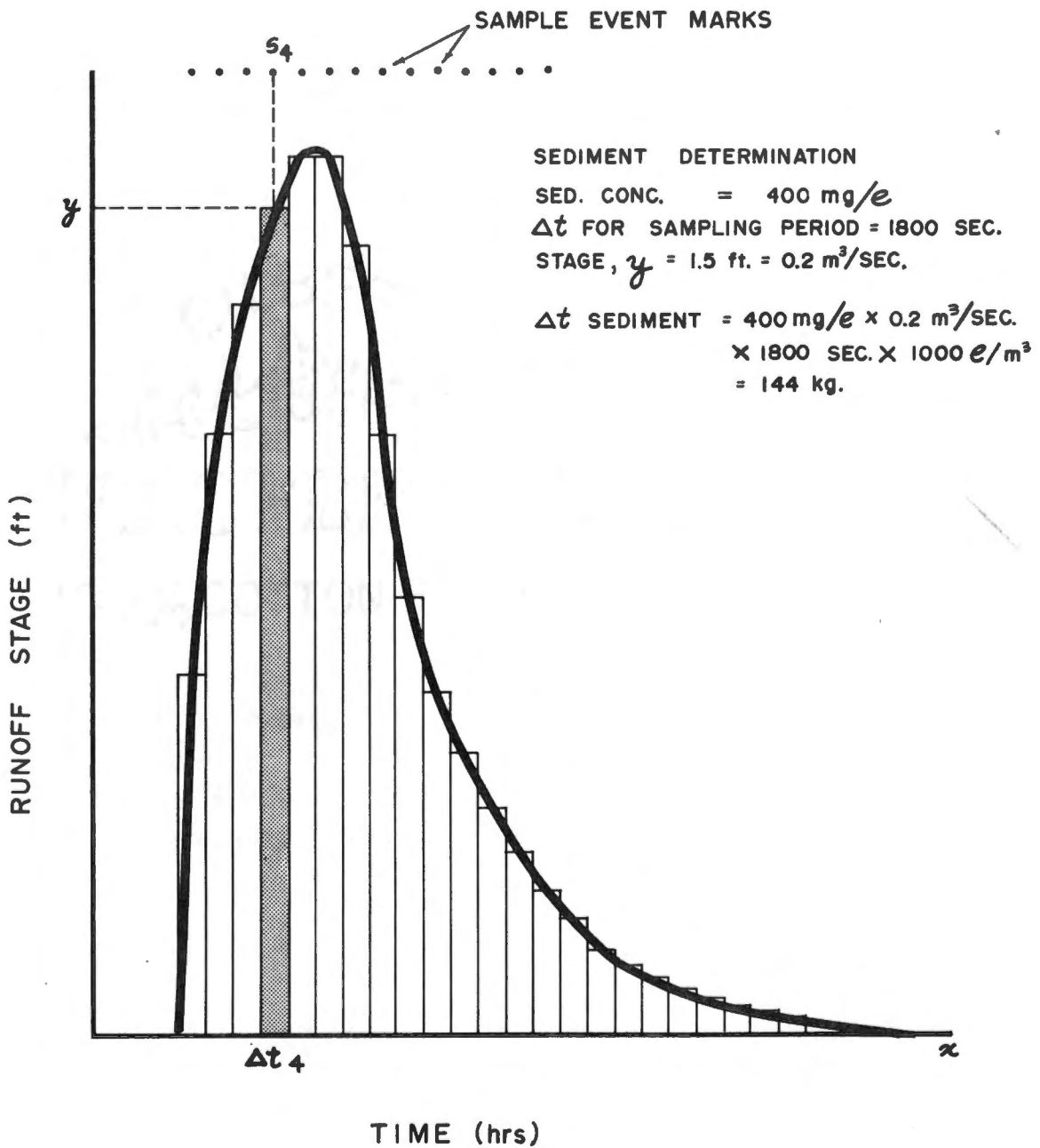


FIGURE 6. Sample runoff hydrograph.

1/3

Turbidity and total suspended matter data were sought as additional information to supporting trends of sediment concentration. The samples obtained during peak flow conditions were identified with the use of the sampler event marker. Station operators numbered each sample as it was removed from the sampling machine. The sample associated with the peak runoff rate was identified by the number of the event mark closest to the time of peak. After analysis, the samples were refrozen and given to representatives of Plant and Soil Science Department for chemical analysis in conjunction with another investigation.

Water Quality Parameters

The sediment concentration was determined by a gravimetric analysis involving evaporation of a known quantity of sample. The sample was thawed and continually stirred with a magnetic bar stirrer in order to keep the sediment in suspension. During the stirring operation, 25 milliliters of sample was piped into an evaporation dish and dried at 105 degrees centigrade. The temperature of 105 degrees was chosen to assure drying of the sample without combustion of the organic matter. The difference in weight between the empty dish and the dish plus the dry residue was the weight of sediment. Sediment concentration was expressed in milligrams per liter which is equivalent to parts per million. The sediment was considered to be almost entirely suspended because observations over a period of months showed little or no bed load remaining in the stream gage approach channels following a rain. ★

Total suspended matter was determined by a gravimetric analysis involving filtration and drying of a known quantity of sample. As with

the sediment analysis, the sample was thawed and stirred. During the stirring process 25 milliliters was piped into a filter, and the filter plus residue were dried at 105 degrees centigrade. The difference in weight between the dry, empty filter and the filter plus dry residue was the weight of total suspended matter. Total suspended matter was expressed in milligrams per liter. The difference in weight between the residue resulting from the sediment concentration determination and the total suspended matter retained by the filter was the weight of the dissolved material which passed through the filter used in the total suspended matter analysis.

Turbidity was determined by a direct colorimetry analysis. The sample was thawed and stirred with a magnetic bar stirrer. During the stirring, 25 milliliters of sample was piped into a small sample bottle and quickly placed into a Hach portable turbidimeter. Measuring the ability of the sample to pass incident light, the turbidimeter produced a direct reading which was approximately proportional to the turbidity (JTU) of the suspended matter in the sample.

III. DATA REDUCTION

Rainfall

Rainfall data were programmed into a digital computer which analyzed depth and time to produce rates in inches per hour as well as total volumes in inches. Conversions to SI units were performed with a hand calculator. Other researchers such as Wischmeier and Smith (47) have shown that rainfall energy and sediment yield are highly related to the maximum 30-minute intensity of a rainstorm. For this reason

all rainfall data used were converted to this parameter. The maximum 30-minute intensity was determined as indicated in the example below from data recorded at watershed 7 on March 23, 1975.

Military Time (hrs)	Time Interval (hrs)	Rainfall Intensity (in/hr)	Interval Accumulation (in)
21,2500	00.0835	2.7546	0.2300
21.5000	00.2500	0.1600	0.0400
22.0000	00.5000	0.0200	0.0100

Maximum depth for a 30-minute duration (I_{30}) =

$$0.230 \text{ in} + 0.040 \text{ in} + 0.01 \text{ in (10 min/30 min)} = 0.273 \text{ in/30 min.}$$

Maximum 30-minute intensity (i_{30}) =

$$0.273 \text{ in/30 min} \times 60 \text{ min/hr} =$$

$$0.546 \text{ in/hr} \times 2.54 \text{ cm/in} =$$

$$1.388 \text{ cm/hr.}$$

The rainfall-erosion (erosion) index, a measure of the kinetic energy associated with rainstorms, was determined as indicated in the example below using data recorded at watershed 7 on March 23, 1975. As previously indicated, the maximum 30-minute intensity for this storm was 0.546 in/hr.

Rainfall Intensity (in/hr)	Interval Accumulation (in)	Kinetic Energy Associated With the Intensity (ft.ton/ac.in)	Kinetic Energy Times Interval Accumulation (ft.ton/ac)
2.7546	0.2300	1059	243.00
0.1600	0.0400	655	26.00
0.0200	0.0100	425	<u>4.25</u>
			Total = 263.25

$EI = \text{erosion index} = \text{kinetic energy} \times 30\text{-min int} \times 0.01.$

$EI = 263.25 \text{ ft.ton/ac} \times 0.546 \text{ in/hr} \times 0.01$

$= 1.496 \text{ ft.ton.in/ac.hr} = 1.021 \text{ m.t.cm/ha.hr.}$

Runoff

Runoff data were programmed into a digital computer which analyzed stage-time relationships and produced rates in inches per hour, as well as total volumes in inches. Conversions to SI units were performed with a hand calculator. To aid in computing sediment yield resulting from individual storms, a number of hydrographs were analyzed without the use of the computer. The total runoff volume was determined by integrating the area under the runoff hydrograph (Figure 6, page 24). Runoff rate as a function of stage was obtained from a rating table associated with the design of the specific weir or flume.

Sediment Yield

As a pumping sampler drew a sample from the stream, the event marker placed a mark on the runoff hydrograph to indicate the time at which the sample was taken (Figure 6). The hydrograph was divided into

segments having a base of one-half hour. Sediment for each segment of the hydrograph was computed as the product of sediment concentration (mg/l) and its associated volume of runoff. Total sediment resulting from a runoff-producing rainstorm was computed by summing these products for the entire hydrograph. A sample calculation using data recorded at watershed 7 on May 31, 1975, is given below in Table 2.

The total sediment resulting from this rainstorm, 1450.29 kg, is the summation of the sediment weight column.

IV. DATA ANALYSIS

Sediment Prediction

For the purpose of sediment prediction, calculations were made of sediment yield resulting from 55 rainstorms involving all five watersheds during a period of 18 months. The number of events was limited by the availability of runoff hydrographs having complete information concerning automatic sampling events. Fifty-five runoff hydrographs were found to be correctly marked, indicating that the pumping sampler had functioned properly. The 55 hydrographs were analyzed for total runoff volume, peak runoff rate, and total weight of sediment. The rainstorms which caused the runoff events were analyzed for maximum 30-minute intensity (I) and the rainfall-erosion index (EI).

To determine the relationship between sediment and the rainfall-runoff parameters, a linear regression analysis was performed on the data resulting from the 55 rainstorms. The data were grouped by growing or dormant season as well as by watershed. In attempting to minimize the variation and standard deviation of regression, a cropping-management

TABLE 2. Data and sample calculation of sediment yield from rainstorm on May 31, 1975.

Sample	Sediment Conc. (mg/l)	Runoff Rate (cfs)	Time Interval (sec)	Runoff Volume* (ft ³)	Sediment Weight** (kg)
1	2998.6	3.500	2700	9450.0	802.49
2	802.0	1.380	1800	2484.0	57.68
3	602.6	0.581	1800	1045.8	17.84
4	490.6	0.318	1800	572.4	7.95
5	456.0	0.214	1800	385.2	4.97
6	420.0	0.147	1800	264.6	3.14
7	2013.0	0.116	1800	208.8	11.90
8	5156.0	0.094	39600	3722.4	<u>544.32</u>
Total					1450.29

*Runoff volume (ft³) is the product of runoff rate (cfs) and the time interval (sec).

**Sediment weight (kg) is the product of sediment concentration (mg/l), runoff volume (ft³) and 28.32 (to convert cubic feet to liters).

factor was applied to the rainfall-runoff data. The cropping-management factors were determined by Jent et al. (23) as multiplicative coefficients for essentially all common cropping situations in Tennessee. The use of the factor was intended to prevent a relationship between sediment and rainfall-runoff parameters being an empirical application to their own particular watershed.

★ To establish the possibility of combining empirical equations, there was a need to determine similarity or variance between seasons within watersheds and between watersheds at Milan. To accomplish this, statistical F tests of homogeneity were performed on the regressions. After determining the relationships between seasons and watersheds, a prediction equation for Milan watersheds was developed with the use of linear regression. A prediction equation was also developed for watersheds near Spring Hill from the data obtained on watershed 6. To account for variance between sections of the State, soil-erodibility factors established by Jent et al. (23) were entered into the regression process. With soil-erodibility factors to account for variance between sections of the State, an overall prediction equation was developed. The equation was tested by several methods.¹ Watersheds 5 and 8 were held as test watersheds and a regression analysis of predicted sediment on observed sediment was performed.² The selected prediction equation was also checked for agreement between predicted and observed values by using the Chi-square test.³ To test the equation further, the sediment yield during one year from watershed 15 was calculated using the selected prediction equation. The sediment from every rainfall-runoff event during a one-year period was calculated. The annual sediment yield was

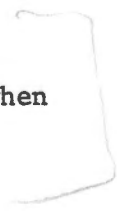
obtained by summation of the individual sediment values. This annual sediment yield was compared to an average annual soil loss computed by use of the universal soil-loss equation.

Turbidity, Total Suspended Matter, and Sediment Concentration

Along with sediment concentration, values of turbidity and total suspended matter were to have been obtained from samples drawn during peak runoff conditions on all five watersheds. However, due to equipment problems discussed in the next chapter, data were analyzed only from watershed 15. Average values of turbidity, total suspended matter and sediment concentration from rainfall-runoff events for individual months during one growing season and one dormant season were calculated and displayed graphically. Rainfall intensity and the resulting energy was found to affect sedimentation to a large degree. For this reason, average values of maximum 30-minute intensity rainfall were also graphically displayed for comparison to the water quality parameters. Average monthly values of peak runoff rates were also displayed along with the rainfall intensities. This graphical analysis was used because a prediction scheme for turbidity or total suspended matter would likely be of little use; whereas a knowledge of trends might have value.



The Statistical Analysis Systems (SAS) utilized at The University of Tennessee Computing Center (UTCC) was employed when statistical procedures were used in the data analysis.



CHAPTER IV

RESULTS AND DISCUSSION

I. SEDIMENT PREDICTION

Work was done on relating sediment concentrations to select runoff and rainfall parameters. Rainfall, runoff, and water quality data were compiled from 55 rainstorms. Sediment was determined as total weight of sediment (kg). Runoff was determined as peak rate of flow (cm/hr) and total volume of flow (m^3). Rainfall parameters were defined as maximum 30-minute intensity (cm/hr) and the erosion index ($m \cdot t \cdot cm/ha \cdot hr$). These data are shown in Tables 12 through 15, Appendix A. With sediment as the dependent variable, and runoff volume, peak runoff rate, rainfall maximum 30-minute intensity, or the rainfall-erosion index as the independent variables; linear regressions were performed on the data from watersheds 7 and 15. Results of the regressions are shown in Tables 3 and 4. The tables show each independent variable explaining more of the variation in the dependent variable as the R-square becomes greater and the coefficient of variation becomes smaller. The best relationship was derived by the regression of sediment on the erosion index; and from the results of the analysis, sediment appeared to be closely related to the erosion index.

The prediction equation for watershed 7 was:

$$y = 220.144 + 499.782 (EI) \quad (1)$$

where y = the sediment in kilograms, and

TABLE 3. Results from regressions of sediment on selected rainfall-runoff parameters for watershed 7.

Regressions	R-square	Sediment Mean (kg)	Standard Deviation	Coefficient of Variation (Percent)
Sediment on Runoff Volume (m^3)	0.45	1919.30	1527.35	79
Sediment on Peak Runoff Rate (cm/hr)	0.44	1919.30	1561.03	81
Sediment on Maximum 30- Minute Intensity Rainfall (cm/hr)	0.53	1919.30	1420.65	74
Sediment on Erosion Index ($m \cdot t \cdot cm/ha \cdot hr$)	0.89	1919.30	682.86	35

TABLE 4. Results from regressions of sediment on selected rainfall-runoff parameters for watershed 15.

Regressions	R-square	Sediment Mean (kg)	Standard Deviation	Coefficient of Variation Percent
Sediment on Runoff Volume (m^3)	0.24	11898.52	14914.64	125
Sediment on Peak Runoff Rate (cm/hr)	0.34	11898.52	13820.39	116
Sediment on Maximum 30- Minute Intensity Rainfall (cm/hr)	0.64	11898.52	10142.21	85
Sediment on Erosion Index ($m \cdot t \cdot cm / ha \cdot hr$)	0.93	11898.52	4525.11	38

EI = the erosion index in meter·tonne·centimeter per
hectare·hour.

Only growing season data were obtained for watershed 7, but watershed 15 provided both dormant and growing season data. This because the pumping sampler on watershed 15 was heated to prevent freezing during the winter months. A seasonal variation in sediment was suspected because of variations in tillage practices, crop cover and rainstorm intensity from season to season. For this reason, separate linear regressions by season were performed on watershed 15.

The prediction equation for the dormant season on watershed 15 was:

$$y = 167.218 + 388.496 (EI). \quad (2)$$

The prediction equation for the growing season on watershed 15 was:

$$y = 3836.818 + 1651.926 (EI). \quad (3)$$

The equations were suspected to be empirical for the watersheds and for seasons. Therefore, a test for homogeneity of regression lines was performed to determine the variance between seasons and watersheds. The comparison seen in Table 5 shows the lack of significance between seasons on watershed 15. Table 6, however, shows a significant difference between the regression lines of watershed 15 and watershed 7.

In an attempt to derive a more broadly applicable equation by taking into account the variation between watersheds, cropping-management factors were introduced as modifications to the erosion indices by a multiplication of the two values. Jent et al. (23) developed

TABLE 5. Regression line comparison of growing and dormant season sediment (kg) on erosion index (m·t·cm/ha·hr) for watershed 15.

	d.f.	Deviation from Regression	
		S.S	M.S.
Growing Season	8	206954730	25869341
Dormant Season	11	156125896	14193263
Pooled Seasons	21	430008679	20476603
Pooled Residuals	19	363080627	19109506
Difference Between Slopes	1	66928052	66928052

3.50. [#] NOTE: Comparison of slopes: $F(1,19) = 66928052/19109506 =$

[#] Not significant at the 95 percent level of probability.

TABLE 6. Regression line comparison of growing-season sediment (kg) on erosion index (m³·t·cm/ha·hr) for watersheds 7 and 15.

	d.f.	Deviation from Regression S.S.	M.S.
Watershed 7	15	6994526	466301
Watershed 15	8	206954730	25869341
Pooled Watersheds	25	264180818	10567232
Pooled Residuals	23	213949257	9302141
Difference Between Slopes	1	50231562	50231562

NOTE: Comparison of slopes: $F(1,23) = 50231562/9302141 = 5.40.*$

*Significant at the 95 percent level of probability.

multiplicative cropping-management factors for most cropping situations in Tennessee. The cropping factors, along with sediment and erosion index data for watershed 15, are shown in Table 14, Appendix A.

Regression of sediment on the adjusted erosion index was performed by season, and the resulting regression lines were compared for variance as before. A comparison between regression lines of growing and dormant season on watershed 15 (Table 7) shows no significant difference. The cropping-management factors, along with sediment and erosion index data for watershed 7, are shown in Table 13, Appendix A. As before, the erosion indices were multiplied by the cropping factors and a linear regression of sediment on the adjusted erosion index was performed. When regression lines between watershed 15 and watershed 7 were compared after adjusting the erosion indices with the cropping-management factors, no significant difference was found. This comparison is shown in Table 8.

The cropping-management factors, which numerically represent the cropping practices employed on the different watersheds, seem to account for the variation between West Tennessee watersheds. Consequently, the linear regressions could constitute a sediment prediction equation for these watersheds. Regression was performed on data from watersheds 7 and 15, and the resulting prediction equation was:

$$y = 87.847 + 17306.208 (EI) (C) \quad (4)$$

where y = the sediment in kilograms,

EI = the erosion index in meter·tonne·centimeter
per hectare·hour, and

TABLE 7. Regression line comparison of growing and dormant season sediment (kg) on adjusted erosion index (m·t·cm/ha·hr) for watershed 15.

	d.f.	Deviation from Regression S.S.	M.S.
Growing Season	8	244458079	30557259
Dormant Season	11	34719786	3156344
Pooled Seasons	21	316495128	15071196
Pooled Residuals	19	279177865	14693571
Difference Between Slopes	1	37317263	37317263

NOTE: Comparison of slopes: $F(1,19) = 37317263/14693571 = 2.54.$ [#]

[#]Not significant at the 95 percent level of probability.

TABLE 8. Regression line comparison of growing-season sediment (kg) on adjusted erosion index (m·t·cm/ha·hr) for watersheds 7 and 15.

	d.f.	Deviation from Regression S.S.	M.S.
Watershed 7	15	5213289	347552
Watershed 15	8	244458079	30557259
Pooled Watersheds	25	289236503	11569460
Pooled Residuals	23	249671368	10855276
Difference Between Slopes	1	39565135	39565135

NOTE: Comparison of slopes: $F(1,23) = 39565135/10855276 = 3.64.$ [#]

[#] Not significant at the 95 percent level of probability.

C = the cropping-management factor.

Linear regression was also performed on sediment and erosion indices obtained from watershed 6 in Middle Tennessee. These data are shown on Table 12, Appendix A. The regression produced the following prediction equation:

$$y = 156.252 + 13196.880 (EI) (C). \quad (5)$$

A test of homogeneity of regression lines was performed between the regression for the West Tennessee watersheds and the Middle Tennessee watershed. The comparison seen in Table 9 shows a significant difference between the regression lines for the two sections of the State. To account for the variation between the two sections of the State, a multiplicative soil-erodibility factor was introduced. Soil-erodibility factors had been established by Jent et al. (23) for the different soils in Tennessee. The soil-erodibility factors, K, for the West Tennessee watersheds, and the Middle Tennessee watershed were 0.39 and 0.32, respectively. These factors were weighted averages because the watersheds had several K values. Previous work done with soil-loss equations by Wischmeier and Smith (47) has shown that soil loss can be a function of the product of a series of related factors. For this reason, the soil-erodibility factor, cropping-management factor, and erosion indices were multiplied, and a regression of this product on sediment was performed. The resulting prediction equation for West Tennessee watersheds was:

$$y = 83.846 + 44374.893 (EI) (C) (K), \quad (6)$$

while that for the Middle Tennessee watershed was:

TABLE 9. Regression line comparison of sediment (kg) on adjusted erosion index (m·t·cm/ha·hr) for the Middle Tennessee watershed and West Tennessee watersheds.

	d.f.	Deviation from Regression S.S.	M.S.
West Tennessee Watersheds	38	974856655	25654122
Middle Tennessee Watershed	4	863426	215856
Pooled Watersheds	44	1186141716	26957766
Pooled Residuals	42	973993229	23190314
Difference Between Slopes	1	212148487	212148487

NOTE: Comparison of slopes: $F(1,42) = 212148487/23190314 = 9.15.*$

*Significant at the 95 percent level of probability.

$$y = 186.826 + 41240.251 (EI) (C) (K). \quad (7)$$

A test of homogeneity was performed for the West Tennessee and Middle Tennessee regressions. A lack of significance determined by the comparison is shown in Table 10, and a regression was performed on the combined data from West and Middle Tennessee. The resulting equation which was selected to predict sediment at the two locations was:

$$y = 90.620 + 45340.511 (EI) (C) (K) \quad (8)$$

where y = the sediment in kilograms,

EI = the erosion index in meter·tonne·centimeter
 per hectare·hour,

C = the cropping-management factor, and

K = the soil-erodibility factor.

Equation 8 was developed with data obtained from watersheds 6, 7, and 15. Data from watersheds 5 in Middle Tennessee and watershed 8 in West Tennessee were withheld to test the selected prediction equation. These data are shown in Table 15, Appendix A. To test the validity of the prediction equation, predicted sediment was compared to observed sediment resulting from selected storms on watersheds 5 and 8 (Table 11). A linear regression of predicted sediment on observed sediment produced an R-square of 0.98, a standard deviation of 264, and a coefficient of variation of 10.25 percent. The line of best fit to the data points had a slope of 41 degrees toward predicted sediment because the equation predicted an average of 240 kilograms too high. Equation 8 was also checked with the Chi-square test, which showed no

TABLE 10. Regression line comparison of sediment (kg) on readjusted erosion index (m·t·cm/ha·hr) for the Middle Tennessee watershed and West Tennessee watersheds.

	d.f.	Deviation from Regression S.S.	M.S.
West Tennessee Watersheds	38	959236503	25243065
Middle Tennessee Watershed	4	852526	213131
Pooled Watersheds	44	995378587	22622240
Pooled Residuals	42	960089029	22859262
Difference Between Slopes	1	35289558	35289558

1.54. # NOTE: Comparison of slopes: $F(1,42) = 35290558/22859262 =$

Not significant at the 95 percent level of probability.

TABLE 11. Predicted and observed sediment from watershed 5 and watershed 8.

Date of Storm	Watershed	Observed Sediment (kg)	Predicted Sediment (kg)
5-10-74	5	305	233
5-15-74	5	209	334
6-01-74	5	1253	1131
6-07-74	5	323	495
6-10-74	8	1663	1332
6-15-74	8	2872	3270
3-22-75	8	2105	2445
4-30-75	8	6427	7228
5-17-75	8	2577	3134

significant difference between predicted sediment and observed sediment at the 95 percent level of probability.

To test the prediction equation over a long period of continued use, a comparison was made between Equation 8 and the universal soil-loss equation when applied to watershed 15. It should be noted, however, that data from watershed 15 were used to develop Equation 8. The selected prediction equation was applied to every rainfall-runoff event that occurred on watershed 15 from May, 1974 through April, 1975. This included one complete growing season and one complete dormant season. Erosion indices, cropping-management factors, and soil-erodibility factors were determined for each rainfall-runoff event. The sediment for each event was calculated using Equation 8, and the summation of the individual sediment values determined the total sediment yield for the year. A typical calculation of sediment, using a rainfall-runoff event which occurred May 2, 1974, on watershed 15 is as follows:

erosion index = 0.538 meter·tonne·centimeter per hectare·hour

cropping-management factor = 0.0306

soil-erodibility factor = 0.39

sediment = $90.62 + 45340.511 (EI) (C) (K)$

$= 90.62 + 45340.511 (0.538) (0.0306) (0.39)$

$= 90.62 + 291.108$

$= 381.73 \text{ kilograms.}$

Substituting appropriate factor values for watershed 15 in the universal soil-loss equation ($A = RKLSCP$),

$$A = (260) (0.39) (0.5) (0.2) (1.0) = 10.14$$

tons per acre (22.72 t/ha) per year. Equation 8 predicted a total yearly sediment yield of 19.49 t/ha from watershed 15.

II. RELATIONSHIPS OF SELECTED WATER QUALITY PARAMETERS TO HYDROLOGIC CONDITIONS AND LAND USE

An attempt was made to relate turbidity, total suspended matter, and sediment concentration to various conditions of rainfall, runoff, and land use. Turbidity, total suspended matter, and sedimentation data were obtained from each watershed; but complete annual data on turbidity and total suspended matter were available only from watershed 15. Only samples drawn at or near the peak runoff rate were analyzed for turbidity and total suspended matter. This was done because emphasis was placed on sedimentation, and only trends of the other two parameters were sought. Sample identification was made by examining the event marks on the runoff hydrograph. However, the sampler on watershed 5 had no event marker and a sampler with an event marker was not installed on watershed 8 until the investigation was approximately half completed. Only the sampler on watershed 15 had continuous electric power to provide heat and to charge the sampler batteries. This prevented malfunctions due to low battery voltage which plagued the other samplers. Operation of all other samplers was discontinued from November until approximately March 15.

To indicate seasonal trends, data were chosen for one growing season and one dormant season. Average monthly values of rainfall maximum 30-minute intensity, peak runoff rate, turbidity, total suspended matter and sediment concentration were compiled from data obtained on

watershed 15. These data are shown in Table 16, Appendix B, and displayed graphically in Figure 7. Figure 7 shows a poor relationship between rainfall or runoff values and the water quality parameters during the growing season. For example, June had next to the lowest average value of maximum 30-minute intensity rainfall but had the greatest values of water quality parameters. The figure does, however, show a close relationship between the hydrologic and water quality parameters during the dormant season. Those months which have the high average values of rainfall and runoff have the larger values of water quality parameters.

Figure 7 clearly shows a general trend to higher average values of turbidity, total suspended matter and sediment concentration during those months when planting, tillage, and sparse vegetative cover are prevalent. It is apparent the watershed is particularly vulnerable to sedimentation during the early part of the growing season. During this time small rainstorms caused large sediment concentrations while later in the season larger rainstorms produced smaller sediment concentrations.

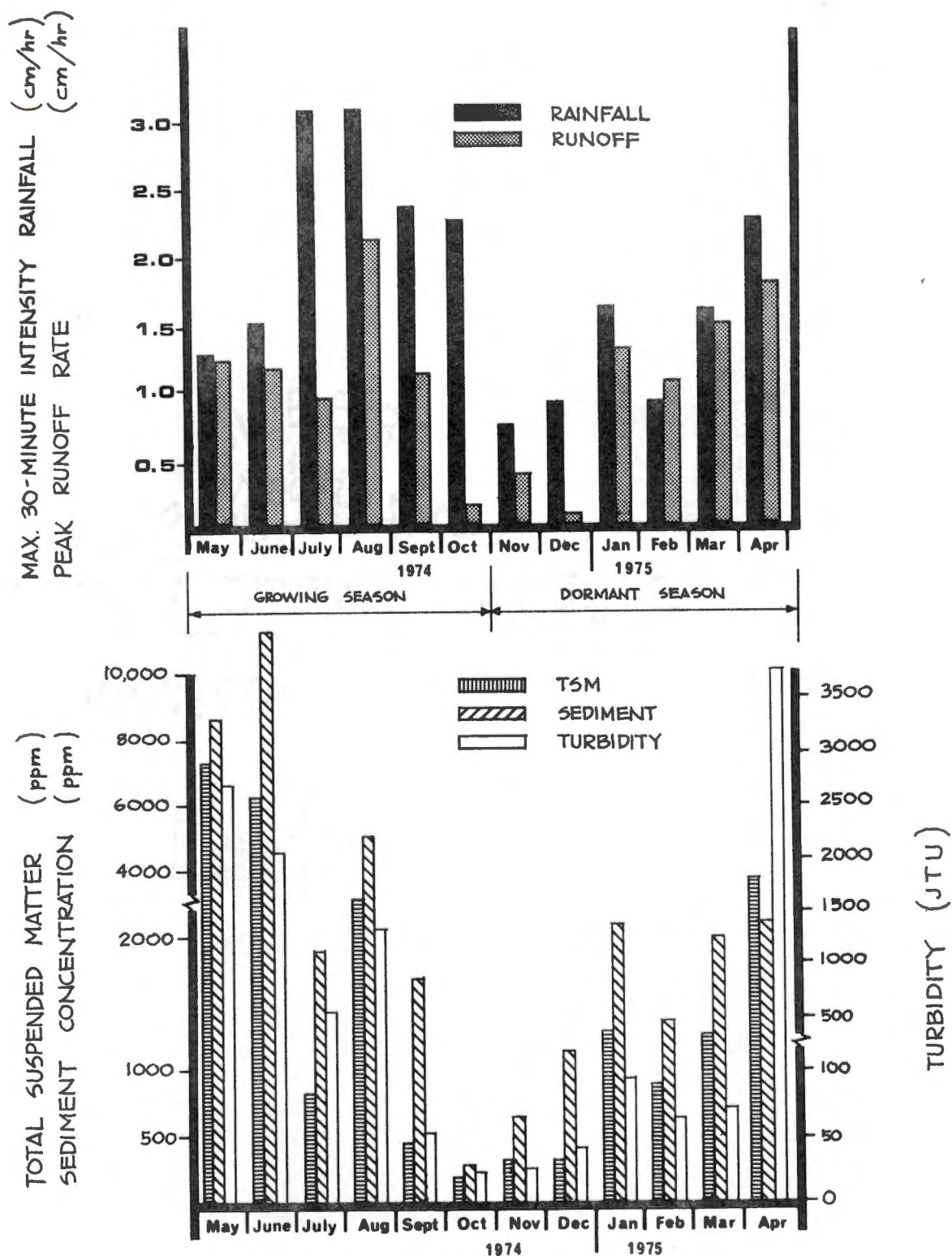


FIGURE 7. Monthly relationships of average maximum 30-minute intensity rainfall, peak runoff rates, and selected water quality parameters.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

Water pollution caused by sedimentation is widespread and affects everyone. Users of polluted water suffer loss of many benefits otherwise derived from clean bodies of water. Existing knowledge indicates that water quality degradation can be caused by a number of agricultural practices, particularly those resulting in sedimentation (the major contributor to water pollution on a volume basis). In spite of considerable progress in recent years, continued research and a more complete understanding of the relationship between sedimentation and water quality remains a pressing need.

A runoff-water quality study was conducted in an attempt to develop a sediment prediction scheme and to establish a relationship between selected water quality parameters and various conditions of rainfall, runoff, and land use. Runoff samples were collected from five watersheds. Three watersheds were located on the Milan Field Station in West Tennessee and two were located on the Middle Tennessee Experiment Station near Spring Hill. Rainfall and runoff data were also obtained from the watersheds.

The runoff samples were analyzed for sediment concentration, total suspended matter, and turbidity. Runoff data were compiled as peak runoff rates, whereas rainfall data consisted of maximum 30-minute

intensities associated with runoff-producing storms. Rainfall and runoff data from a selected number of rainstorms were further reduced to rainfall-erosion (erosion) indices and total runoff volumes, respectively. Sedimentation data were expressed as total sediment yield from each of the selected storms. Linear regressions performed on sediment and various rainfall-runoff parameters showed sediment to be highly dependent on the erosion index. With the aid of cropping-management factors and soil-erodibility factors, a sediment prediction equation was developed. The equation which was applicable to all five watersheds had the form: $\text{Sediment} = f(\text{erosion index, cropping-management factor, and soil-erodibility factor})$.

Sediment concentration, total suspended matter, and turbidity data were computed as average monthly values; and these data were displayed graphically to show monthly relationships of the water quality parameters to rainfall intensities, runoff rates, and land use.

II. CONCLUSIONS

Results of this study indicate that developing sediment prediction equations applicable to several watersheds in various locations is possible. It is also possible to establish useful relationships between sediment concentration, turbidity, and total suspended matter and various conditions of rainfall, runoff, and land use.

The following conclusions were drawn from the results of the study:

1. Sediment yield is dependent to a very low degree on runoff peak rate and volume. Sediment yield is slightly dependent on maximum

30-minute intensity rainfall and highly dependent on the rainfall-erosion (erosion) index.

2. A sediment prediction equation of the form, $\text{Sediment} = f$ (erosion index), is empirical for an individual watershed. Additional parameters such as cropping-management and soil-erodibility factors must be included to make the equation applicable to various watersheds.

3. Sediment concentration, total suspended matter, and turbidity are not closely related to maximum 30-minute intensity rainfall or peak runoff rates during the growing season. During the dormant season the water quality parameters are closely related to the rainfall and runoff parameters.

4. Concentrations of sediment, turbidity, and total suspended matter found in runoff reach maximum values during the time of maximum tillage and sparse vegetative cover.

III. RECOMMENDATIONS FOR FURTHER STUDY

The work reported in this thesis forms an initial part of research directed toward the development of a series of models to predict quality of runoff water from agricultural land. Additional water quality parameters including bacteria levels, oxidation demand, and chemical levels should be investigated for the possibility of developing prediction techniques.

Land-use practices were not varied through a wide range during the 18 months of data collection. For this reason, the investigation reported in this thesis should be continued to include a broader spectrum of land use.

During this investigation it was determined that turbidity was a parameter obtained quickly and easily with little error. It seems worthwhile therefore, to investigate the possibility of developing a relationship between sediment and turbidity. This would involve entirely new technology, because at present there is no known method for correlating the turbidity and the weight concentration of suspended matter. Such a relationship would be extremely valuable because sediment, a major water pollutant, is also a major contributor to the level of turbidity.

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APPENDICES

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APPENDIX A

SEDIMENT PREDICTION DATA

The data used in developing and testing equations to predict sediment are given in Tables 12 through 15.

TABLE 12. Watershed 6 data used in developing equations to predict sediment.

Date of Storm	Runoff Total Volume (m ³)	Peak Runoff Rate (cm/hr)	Sediment (kg)	Rainfall Max. 30-Minute Intensity (cm/hr)	Rainfall-Erosion Index (EI) (m·t·cm/ha·hr)	Cropping-Management Factor	Soil-Erodibility Factor
04-12-74	292.8	0.01	179.8	1.08	0.64	0.010	0.32
06-01-74	1940.4	0.06	2665.8	1.94	7.97	0.024	0.32
06-05-74	864.2	0.03	1998.6	2.83	6.20	0.020	0.32
06-06-74	1853.5	0.12	3187.6	4.46	11.67	0.020	0.32
03-29-75	1730.2	0.09	1221.5	2.08	5.10	0.018	0.32
04-02-75	1160.5	0.03	708.4	1.98	2.06	0.018	0.32

TABLE 13. Watershed, 7 data used in developing equations to predict sediment.

Date of Storm	Runoff Total Volume (m ³)	Peak Runoff Rate (cm/hr)	Rainfall Max. 30- Minute Intensity (cm/hr)	Sediment (kg)	Rainfall- Erosion Index (EI) (m·t·cm/ha·hr)	Cropping- Management Factor	Soil- Erodibility Factor
05-31-74	459.7	0.13	2.29	7618.9	12.98	0.033	0.39
05-31-74	718.1	0.14	0.91	1537.9	2.53	0.033	0.39
06-06-74	258.9	0.12	1.29	3813.9	5.01	0.044	0.39
06-10-74	101.5	0.12	1.14	1319.5	1.66	0.044	0.39
10-15-74	190.1	0.02	2.20	3306.7	8.13	0.023	0.39
10-15-74	446.9	0.01	0.28	490.3	0.49	0.023	0.39
03-22-75	1646.9	0.37	2.79	1834.9	5.55	0.019	0.39
03-23-75	315.6	0.12	1.39	413.6	1.02	0.019	0.39
04-18-75	57.4	0.01	2.86	1435.8	3.89	0.022	0.39
04-30-75	3446.3	0.21	3.91	5172.9	13.46	0.022	0.39
05-07-75	3370.8	0.91	4.44	8381.1	14.34	0.033	0.39
05-17-75	2201.3	0.13	1.61	324.7	5.22	0.033	0.39
05-15-75	2547.6	0.30	1.97	929.3	2.65	0.033	0.39
05-26-75	653.4	0.13	3.12	3766.9	5.80	0.033	0.39
05-28-75	1152.3	0.31	3.25	3901.5	6.19	0.033	0.39
05-31-75	513.5	0.14	2.20	1450.3	2.35	0.033	0.39
06-09-75	223.4	0.06	2.08	1872.1	2.43	0.044	0.39

TABLE 14. Watershed 15 data used in developing equations to predict sediment.

Date of Storm	Runoff Total Volume (m ³)	Peak Runoff Rate (cm/hr)	Sediment (kg)	Rainfall Max. 30-Minute Intensity (cm/hr)	Rainfall-Erosion Index (EI) (m·t·cm/ha·hr)	Cropping-Management Factor	Soil-Erodibility Factor
05-02-74	2723.1	3.27	7619.4	3.36	14.36	0.031	0.39
05-05-74	511.0	0.31	405.9	0.43	0.67	0.031	0.39
05-31-74	3922.7	1.14	1408.8	0.91	2.53	0.031	0.39
06-10-74	2182.8	1.65	1892.6	1.14	1.63	0.063	0.39
08-09-74	1666.8	1.14	51272.4	4.78	31.62	0.096	0.39
08-11-74	5649.5	1.98	15422.2	1.98	8.46	0.096	0.39
09-27-74	632.9	0.11	3416.8	1.06	2.14	0.096	0.39
09-28-74	7071.8	2.59	64351.1	4.98	38.42	0.096	0.39
10-15-74	391.8	0.09	3018.4	2.20	13.13	0.013	0.39
12-15-74	19.1	0.01	398.1	0.55	0.69	0.024	0.39
12-29-74	297.8	0.05	239.4	0.26	0.36	0.024	0.39
01-03-75	409.3	0.08	209.2	0.46	0.30	0.024	0.39
01-08-75	26984.7	2.85	4645.5	4.14	10.99	0.024	0.39
01-10-75	2880.2	0.65	1905.3	0.63	4.47	0.024	0.39
02-01-75	2431.5	0.39	251.2	0.34	0.33	0.024	0.39
02-04-75	1131.6	0.17	138.5	0.23	0.13	0.024	0.39
02-11-75	318.8	0.10	132.7	0.39	0.14	0.024	0.39

TABLE 14. (continued)

Date of Storm	Runoff Total Volume (m ³)	Peak Runoff Rate (cm/hr)	Sediment (kg)	Rainfall Max. 30- Minute Intensity (cm/hr)	Rainfall- Erosion Index (EI) (m·t·cm/ha·hr)	Cropping- Management Factor	Soil- Erodibility Factor
02-16-75	108.8	0.05	167.2	0.66	0.15	0.024	0.39
03-22-75	7818.4	1.79	2654.4	2.79	5.55	0.024	0.39
04-18-75	901.3	1.03	2051.6	2.86	3.89	0.030	0.39
04-30-75	8404.9	2.11	7182.4	3.91	13.46	0.030	0.39
05-07-75	19637.9	4.19	7795.9	4.44	14.34	0.030	0.39
06-09-75	1355.2	0.57	206.4	2.08	2.43	0.030	0.39

TABLE 15. Data used to test the equation selected to predict sediment.

Date of Storm	Test Water-shed	Runoff Total Volume (m ³)	Peak Runoff Rate (cm/hr)	Sediment (kg)	Rainfall Max. 30-Minute Intensity (cm/hr)	Rainfall-Erosion Index (EI) (m ³ ·cm/ha·hr)	Cropping-Management Factor	Soil-Erodibility Factor
05-10-74	5	1175.2	0.04	305.4	0.65	1.09	0.009	0.32
05-15-74	5	1166.8	0.04	209.7	1.17	1.87	0.009	0.32
06-01-74	5	2137.1	0.24	1253.2	1.94	7.97	0.009	0.32
06-07-74	5	1200.3	0.47	323.1	2.03	3.10	0.009	0.32
06-10-74	8	1191.2	0.61	1663.6	1.14	1.63	0.043	0.39
06-15-74	8	1399.3	0.92	2872.9	2.88	4.18	0.043	0.39
03-22-75	8	1279.6	1.14	2105.6	2.79	5.55	0.023	0.39
04-30-75	8	1446.6	1.44	6427.7	3.91	13.46	0.030	0.39
05-17-75	8	2639.6	1.26	2577.4	4.44	5.21	0.033	0.39

APPENDIX B

RAINFALL, RUNOFF-QUALITY DATA

The data used to graphically display trends in water quality parameters are given in Table 16.

TABLE 16. Monthly relationships of maximum 30-minute intensity rainfall, peak runoff rate, and selected water quality parameters.

Year	Month	Rainfall Max. 30- Minute Intensity (cm/hr)*	Runoff Peak Flow Rate (cm/hr)*	Turbidity (JTU)*	Total Suspended Matter (ppm)*	Sediment Concentration (ppm)*
1974	May	1.25	1.21	2728	7075	8644
1974	June	1.44	1.19	2188	6255	10635
1974	July	3.09	0.92	523	834	1842
1974	Aug	3.11	2.17	1300	3443	5048
1974	Sept	2.39	1.09	50	425	1723
1974	Oct	2.20	0.09	20	150	232
1974	Nov	0.67	0.36	34	283	635
1974	Dec	0.89	0.03	39	298	1098
1975	Jan	1.62	1.24	97	1288	2598
1975	Feb	0.96	1.01	61	887	1396
1975	Mar	1.60	1.51	75	1233	2081
1975	Apr	2.27	1.86	3750	3900	2959

*Figures represent the average monthly peak values.

VITA

John Dardis Simmons was born in New York, New York, on March 11, 1942. He started elementary school in Bay Shore, Long Island, New York, and completed this phase of his education in Knoxville, Tennessee, after his family moved to Knoxville in 1955. He was graduated from Knoxville Catholic High School in 1960. After two years at The University of Tennessee, he enlisted in the United States Navy and served for six years.

In January, 1971, he re-entered The University of Tennessee and in December, 1973, he received a Bachelor of Science degree in Agricultural Engineering. Supported by a graduate research assistantship, he immediately entered The Graduate School at The University of Tennessee and began study toward a Master of Science degree in Agricultural Engineering.